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This paper was prepared for submittal to the
Probabilistic Safety Assessment and Management 4
International Conference on Probabilistic Safety Assessment and Management
New York City, NY
September 13-18, 1998

April 3, 1998



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Risk Ranking Methodology for Chemical Release Events

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1 Introduction

Risk ranking schemes have been used in safety analysis to distinguish lower risk accidents from higher risk accidents. This is necessary to identify those events that might warrant additional study or quantitative analysis and to ensure that any resources allocated for risk reduction are properly directed.

A common method used for risk ranking utilizes risk matrices. These are typically 3x3 or 4x4 matrices, having event consequences along one axis and event frequency along the other. Each block on the risk matrix represents some level of risk, and blocks presenting similar risk are often grouped together into one of three or four risk regions. Once a risk matrix has been identified, events are placed on the matrix based on an estimate of the event consequence and event frequency. Once the risk of each block on the matrix is defined, the relative risk of the events can be found based on where they are placed on the matrix.

In most cases, the frequency axis of the matrix has numerical values associated with it, typically spanning several orders of magnitude. Often, the consequence axis is based on a qualitative scale, where consequences are judgment based. However, the consequence scale generally has implicit quantitative values associated with it, which may or may not be recognized. Risk regions are often arbitrarily assigned (or assigned on the basis of symmetry). This presents a problem in that if the blocks of the risk matrix are incorrectly grouped, then incorrect conclusions can be drawn about the relative risk presented by events at a facility.

This paper first describes how risk matrices have typically been established in the past. Problems associated with these risk matrices are identified and discussed. A methodology for logically establishing risk matrices, with specific application to chemical risk, is provided.

2 Qualitative Risk Matrices and Relative Risk

Three types of risk matrices are commonly used for risk ranking. A purely qualitative risk matrix will have its bins defined in descriptive or qualitative terms. A purely quantitative risk matrix has its bins defined in measurable or quantitative terms. Relative or absolute numerical scales are used on quantitative matrices, whereas scales on qualitative matrices are relative but not numerical. The third type of risk matrix is a hybrid: a semi-quantitative matrix with one scale (usually frequency) expressed quantitatively, while the other scale is expressed qualitatively.

Risk is defined as the product of frequency and consequence. For a quantitative matrix, the risk is then simply expressed as a numerical point estimate or range. For qualitative and semi-quantitative matrices, the risk for each block cannot be expressed numerically, but is simply the combination of the frequency bin description or value, and the consequence bin description. For these matrices, the risk for a given block can only be directly compared with some, but not all of the other blocks. A relative risk comparison can be made between Block A and Block B only when there is an unambiguous relationship between them. An ambiguous relationship exists in these two situations:

1. If A has a greater frequency bin than B, and a smaller consequence bin than B.
 2. If A has a greater consequence bin than B, and a smaller frequency bin than B.
- For these ambiguous situations, meaningful conclusions cannot be drawn regarding the risk that these blocks present with respect to one another.

Figure 1 shows a hypothetical qualitative risk matrix. The risk blocks connected by arrows can be directly compared to each other, and the arrows are shown to progress in the direction of increasing risk. Any block that can be reached along the paths of the arrows can be compared to any other along that path. A risk comparison is ambiguous for blocks that cannot be connected by the arrows. For example, how can we compare the risk of an accident with a frequency of "Definite Maybe" and "Minor" consequences to one having a frequency of "Once in a Blue Moon" with "Major" consequences?

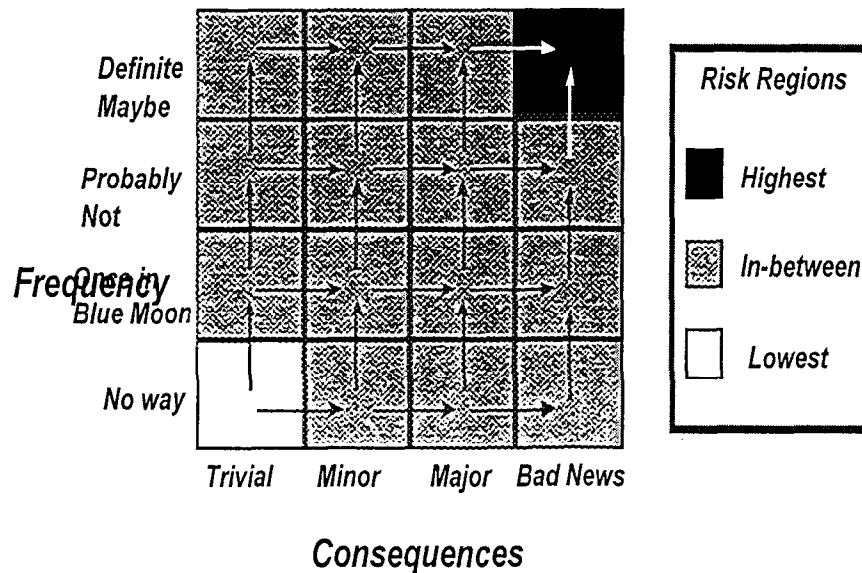


Figure 1. A 4x4 Risk Matrix: arrows show relationships of increasing risk.

Because of the limitations in making risk comparisons, qualitative and semi-quantitative matrices have very limited value. It makes no sense to attempt risk groupings of the blocks, as the only logical grouping is the obvious one shown in Figure 1: the lower left corner is the lowest risk group, the upper right corner is the highest risk group, and everything else is in the middle. Any subdivision of the

middle group is fraught with peril, as blocks having lower risk will be grouped with others having higher risk, and some blocks in a “higher-risk” group may have lower risk than some blocks in the “lower risk” group, since any comparison among them is ambiguous. There is no other way to logically group the blocks for the qualitative and semi-quantitative matrices.

Although the only logical way to group blocks on a qualitative risk matrix is shown in Figure 1, many other unfounded variations have been applied. Usually, there is no distinction as to the type of accident or facility a given matrix might be best applied to. Often, there is no logical basis for the risk groupings. Faulty decisions have been made on the acceptability of the risk, based on such unfounded matrices. This aspect is discussed further in References [1] and [2].

3 Establishing Useful Relative Risk Matrices

We illustrate an example here of risk matrix development for chemical release events. Two risk matrices are developed: one for workers and one for the public. Each is a 4x4 matrix, as shown in Figure 2. The first step is to assign numerical values to the frequency and consequence axes. These can be dimensionless, serving to establish the relative importance of each bin. The maximum relative risk for each block is easily calculated as the product of the upper limit of the range on the frequency bin and the upper value of the consequence bin. These values do not represent absolute risk and cannot be compared to risk values from some other risk matrix. The frequency categories were established as follows:

I: 0.1 - 1 /yr	III: 10^{-4} - 10^{-2} /yr
II: 10^{-2} - 0.1 /yr	IV: 10^{-6} - 10^{-4} /yr

The consequence categories were established as follows, and reflect possible ranges of consequences that each population group might be exposed to:

- I: No noticeable impact. *Workers:* exposure to chemical concentration less than TLV-TWA¹; in relative terms, < 1; *Public:* exposure to chemical concentration less than one-tenth the TLV-TWA; in relative terms, < 0.1.
- II: Minor impact; reporting may be required. *Workers:* exposure to chemical concentration between TLV-TWA and ERPG-2² or equivalent; worker injury; in relative terms, 1 - 100; *Public:* exposure to chemical concentration between one-tenth the TLV-TWA and ERPG-1³ or equivalent; in relative terms, 0.1 - 10.

¹TLV-TWA: Threshold Limit Value, Time Weighted Average, is the maximum concentration level of hazardous material to which a worker can be exposed for 8 hours/ day, 40 hours/week

²ERPG-2: Emergency Response Planning Guide, Level 2, as defined by the American Industrial Hygiene Association, is the maximum airborne concentration level of hazardous material below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their ability to take protective action.

³ ERPG-1: Emergency Response Planning Guide, Level 1, as defined by the American Industrial Hygiene Association, is the maximum airborne concentration level of hazardous material below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor

III: Significant impact. *Workers*: exposure to chemical concentration between ERPG-2 or equivalent and ERPG-3⁴ or equivalent; lost-time injury, chemical exposure causing significant discomfort or which is somewhat disabling; in relative terms, $10^0 - 10^4$. *Public*: exposure to chemical concentration between ERPG-1 or equivalent and ERPG-2 or equivalent, i.e. measurable chemical exposure; in relative terms, $10 - 100$.

IV: Severe impact. *Workers*: exposure to chemical concentration above ERPG-3 or equivalent i.e. death, disability, potential severe short-term health effects; in relative terms, $10^4 - 10^6$. *Public*: exposure to chemical concentration between ERPG-2 or equivalent and ERPG-3 or equivalent; in relative terms, $100 - 10^4$.

The assignment of relative values of consequence, as given above, is necessary, as the matrices require numerical scales. The consequence scale should be expressed in terms reflective of the relative magnitude of harm or injury that would be associated with exposure to a certain chemical concentration. For some chemicals, the numerical values of ERPG-2 and ERPG-3 concentrations are different by less than a factor of two; in other cases, they may differ by an order of magnitude. But, the magnitude of harm or injury associated with any of the ERPG concentrations is defined, and the same definitions apply for all chemicals. Thus, it is more appropriate to define a scale for chemical consequences representing the level of harm from an exposure, rather than the concentration to which one was exposed. The relative values assigned here are subjective and debatable. However, they were selected for use here to illustrate the methodology and necessary thought processes.

Values of harm or consequence should be related to a reference point. For example, the harm associated with exposure to the TLV-TWA concentration could be set equal to one. If it is assumed that below the TLV, the consequence associated with exposure is linear, then exposure to a concentration of one-tenth the TLV-TWA would give a value for the consequence scale of 0.1.

At the ERPG-1 level, one may experience some mild adverse health effects or perceive an objectionable odor. This is clearly a more significant consequence when compared to an exposure to the TLV-TWA, where continuous exposure for 40 hours a week would not result in any health effects. Then it is reasonable to assign the health effects associated with exposure at the ERPG-1 level a value of 10.

At the ERPG-2 level, one may experience reversible health effects. This consequence was judged to be 10 times more severe than the consequences one might experience at exposure to the ERPG-1 concentration. The value assigned to the ERPG-2 health effects on the consequence scale is then 100.

At the ERPG-3 level, one may experience irreversible health effects. Because these health effects could include permanent disability, this was thought to be considerably more severe than exposure at the ERPG-2 concentration. Thus, the ERPG-3 consequences were assigned a value 100 times greater than the ERPG-2 consequences, or 10,000. Another way to look at this is in terms of a trade-off. It was thought to be reasonable to consider the exposure of 100 individuals (either

⁴ERPG-3: Emergency Response Planning Guide, Level 3, as defined by the American Industrial Hygiene Association, is the maximum airborne concentration level of hazardous material below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life threatening effects.

workers or members of the public) to the ERPG-2 concentration, resulting in temporary but significant effects, equal to the exposure of 1 individual (also in either population) to the ERPG-3 concentration, which could result in permanent effects.

The last consequence of interest is death, and this was utilized here only for the development of the worker risk matrix. Again, this health effect was thought to be significantly more severe than the previous level, and the consequences were assigned a value 100 times greater than the ERPG-3 consequences, resulting in a numerical value of 10^6 for death. In terms of a trade-off, it could be considered that exposure of 100 workers to the ERPG-3 concentration, potentially resulting in permanently disabling effects, was approximately equal to the exposure of 1 worker to a lethal concentration, which would result in death.

The numerical values established for the matrix axes can be utilized to provide numerical values for risk for the blocks on the matrix. To be simple and conservative, the highest values of frequency and consequence corresponding to a given block were used to determine a value for risk for that block. These values are indicated on Figure 2.

The next step was to identify blocks of the matrices representing similar risk. This was done by establishing four risk bins, Risk Levels 1 through 4. Risk Level 1 represents the lowest risk, and Risk Level 4 represents the highest risk.

Binning and Risk Level selection were based on two premises. These are subjective and debatable, but the criteria here serve to illustrate the methodology.

1. The risk associated with an event in Frequency Category I ($0.1 - 1$ /yr) and resulting in the upper bound Category I consequence to the public (0.1) would be the upper bound for risk in Level 1. Thus, risk in Level 1 $< 1 * 0.1 = 0.1$.
2. The risk associated with an event in Frequency Category II (event occurring sometime during the life of the facility, $10^{-2} - 0.1$ /yr) resulting in the death of a worker (i.e. upper bound for Category 4 consequence for workers, 10^6) would be the lower bound for risk in Level 4. Thus, risk in Level 4 $> 10^{-2} * 10^6 = 10^4$.

Risk levels 2 and 3 were assigned to fit between these bounds as noted below:

Risk Level 1: risk value ≤ 0.1	Risk Level 3: $10 < \text{risk value} \leq 10^4$
Risk Level 2: $0.1 < \text{risk value} \leq 10$	Risk Level 4: risk value $> 10^4$

Conseq. Category IV (10^4 - 10^6)			$1e-5$	$1e6$
Conseq. Category III(10^2 - 10^4)	1			
Conseq. Category II (1 - 10^2)	$1e-2$	1	10	
Conseq.	$1e-4$	$1e-2$	0.1	1

Conseq. Category IV (10^2 - 10^4)	1			
Conseq. Category III(1 - 10^2)	$1e-2$	1	10	
Conseq. Category II (0.1 - 1)	$1e-3$	0.1	1	10
Conseq.	$1e-5$	$1e-3$	$1e-2$	0.1

Category I(< 1)					Category I(< 0.1)				
Worker Risk	IV (10 ⁻⁶ - 10 ⁻⁴)	III (10 ⁻⁴ - 10 ⁻²)	II (10 ⁻² - 0.1)	I (0.1 - 1)	Public Risk	IV (10 ⁻⁶ - 10 ⁻⁴)	III (10 ⁻⁴ - 10 ⁻²)	II (10 ⁻² - 0.1)	I (0.1 - 1)
	Frequency Category					Frequency Category			
	Risk Level 1					Risk Level 3			
	Risk Level 2					Risk Level 4			

Figure 2. Worker & Public risk matrices for chemical release events.

The numerical values on each risk matrix for each block (obtained by multiplying the appropriate consequence value and frequency value) were compared to the risk range values given above. The same risk range values were applied to both workers and the public. This allowed each of the risk blocks to be assigned a Risk Level. In Figure 2, blocks belonging to the four risk levels are distinguished by different shading. The shading of each block will allow one to determine if an event placed in that risk block presents more, less, or similar risk than an event in another risk block.

Once the risk regions have been established on the risk matrix, the analyst needs only to estimate the frequency and consequences associated with an event well enough to place the event into a frequency and a consequence bin. The event can then be placed on the matrix, and the relative risk level for the event will be determined. An approach similar to this was utilized for the Atomic Vapor Laser Isotope Separation Facility safety analysis at Lawrence Livermore National Laboratory [3].

The approach just outlined can be followed to establish chemical relative risk matrices. However, useful information on the relative risk of events may not always result. For example, after reviewing the chemical events identified for a facility, the analyst may find that all events fall into the same risk region. It may be sufficient to know this, or the analyst may want to adjust the frequency or consequence scales to provide a greater discrimination among the events.

4 Closing Remarks

A risk matrix can be a useful tool to present the results of simplified risk analysis, helping one to gain insight into the relative risks of various scenarios that might be encountered in a given system. When developed quantitatively with axes constructed to be relevant to the facility and operations being studied, risk evaluations can be defined logically. Logic-based risk evaluations can facilitate management decisions such as the authorization of operations. It can also help optimize resources by showing where to concentrate efforts for more detailed analysis or for risk reduction activities.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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